LDCM On-Orbit Cal/Val Considerations

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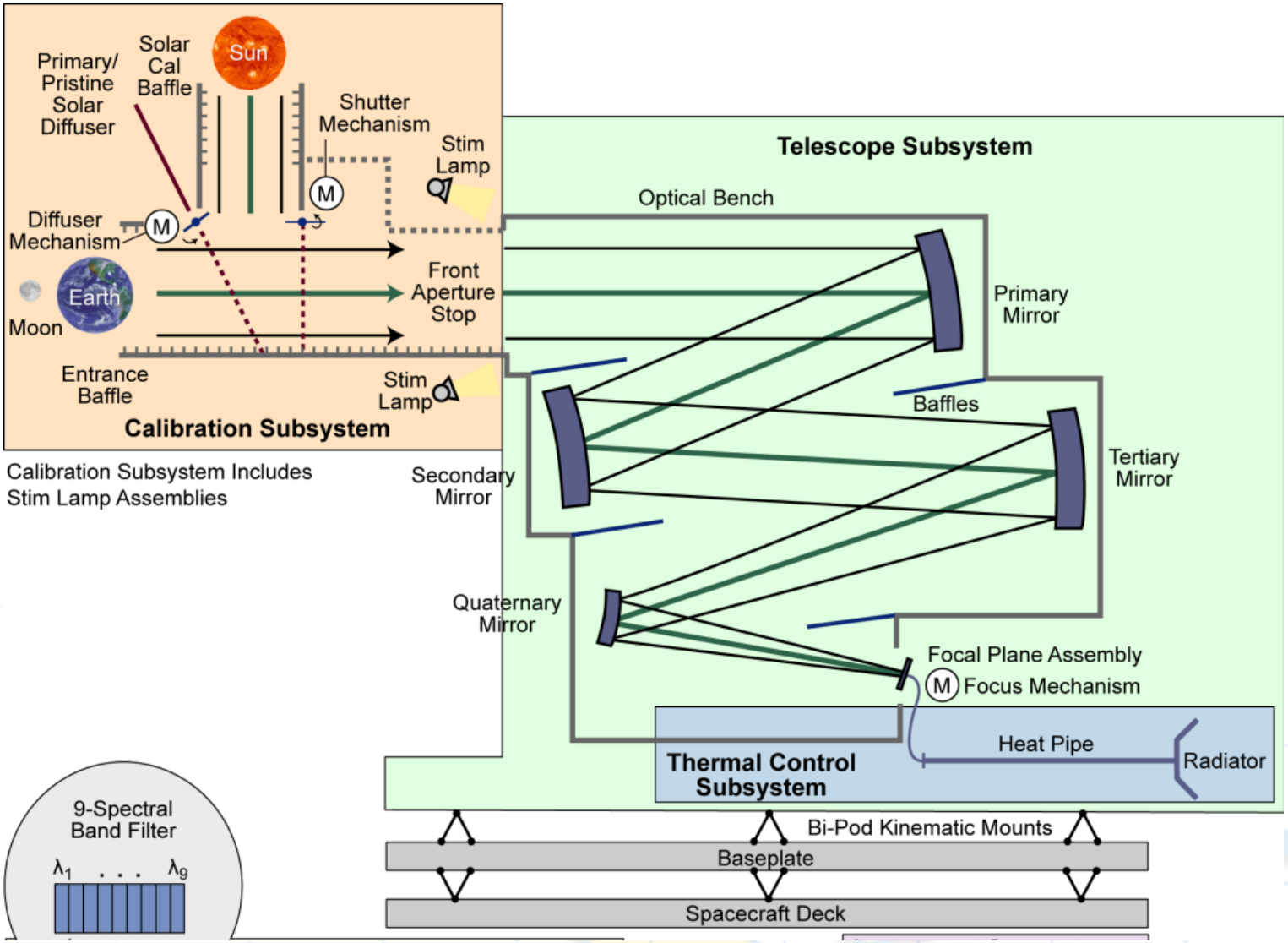
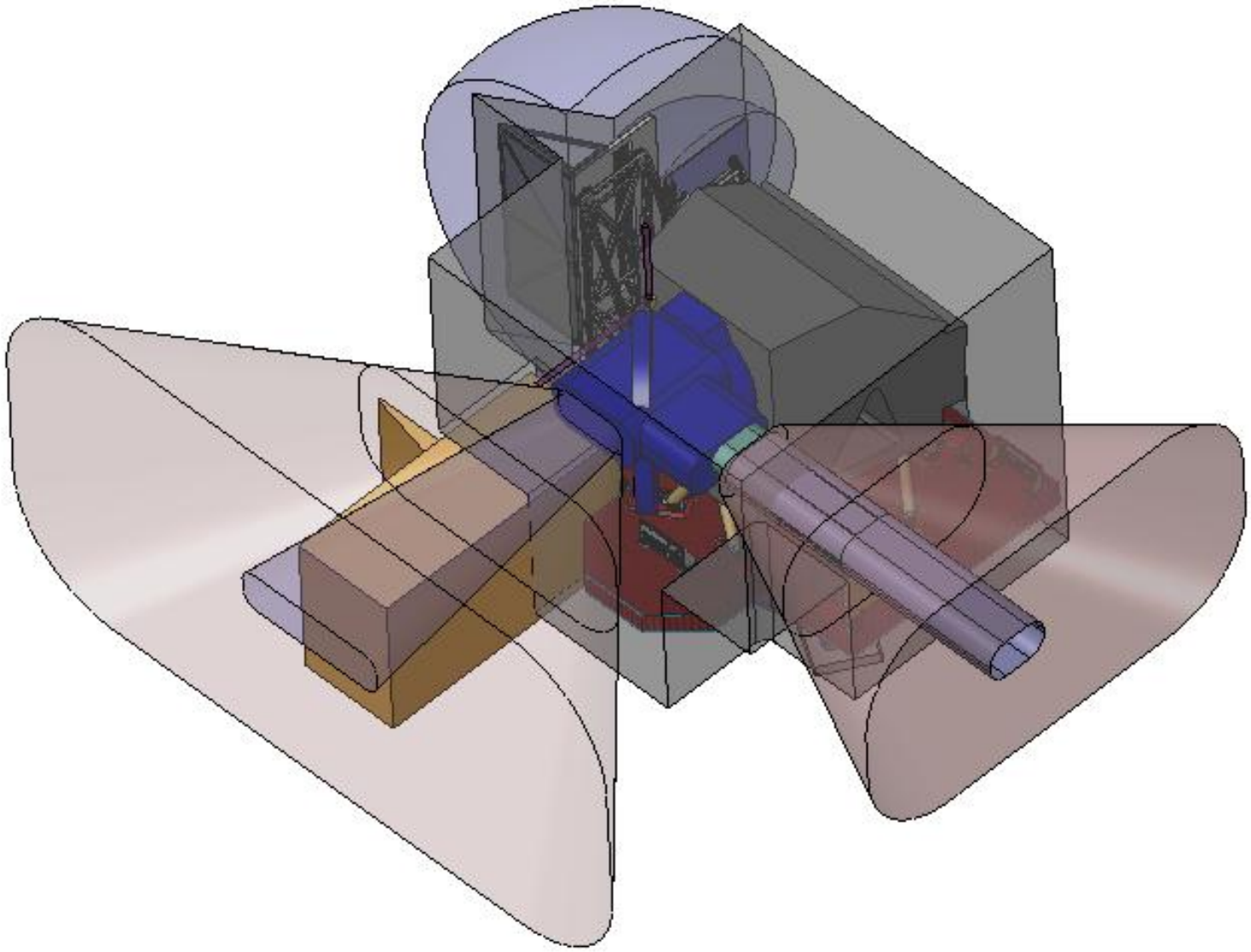
Topics

- Instrument Design Review/Calibration Implications
- Preliminary Orbit and Ascent Plan
  - Under-fly/tandem flying scenarios
- Commissioning Phase
- Calibration Activities
  - Roles
    - Instrument Providers
    - Cal/Val Team/IAS
  - Acquisitions/Maneuvers
  - Analyses/Verifications
- Operations Phase
  - Calibration Activities

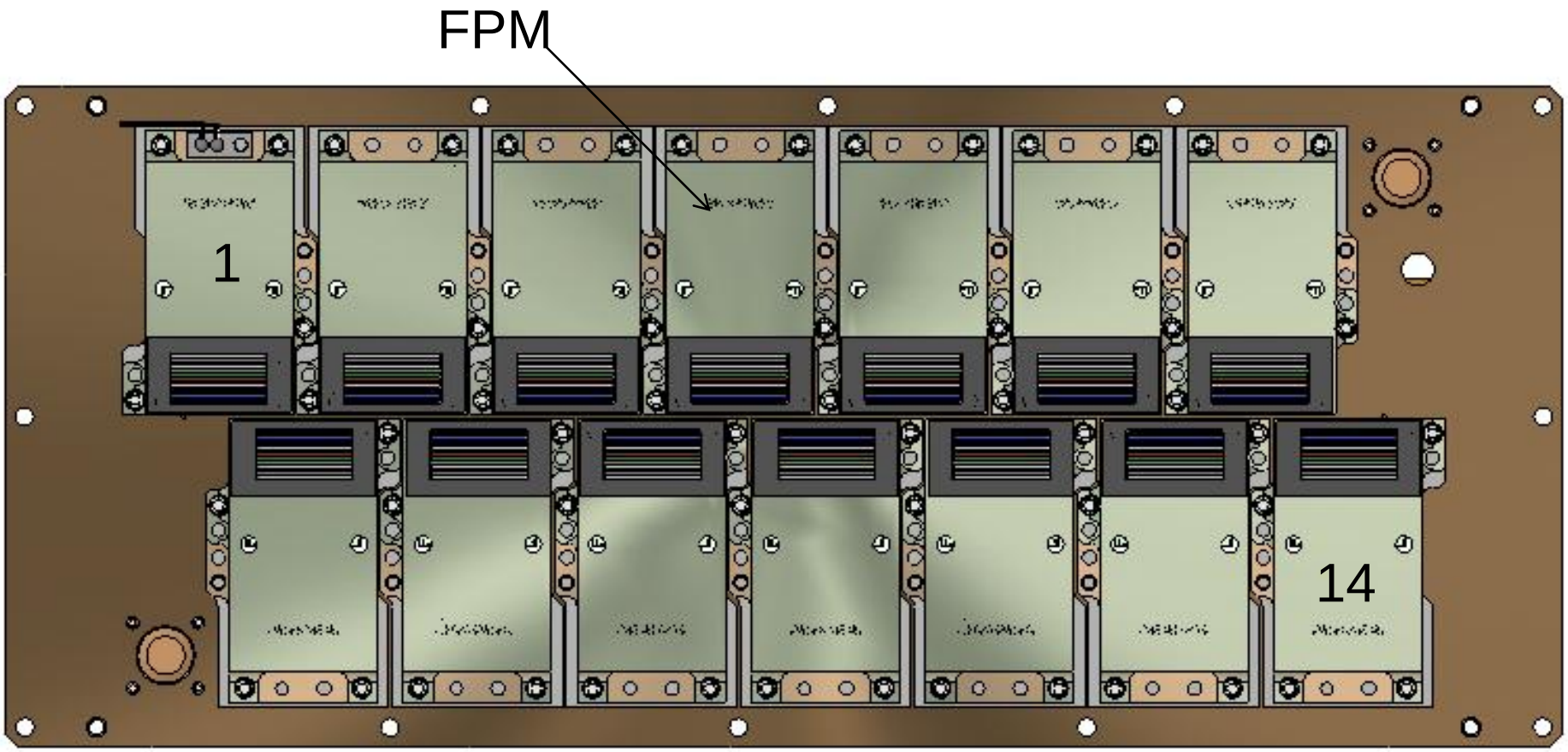
OLI Functional Block Diagram



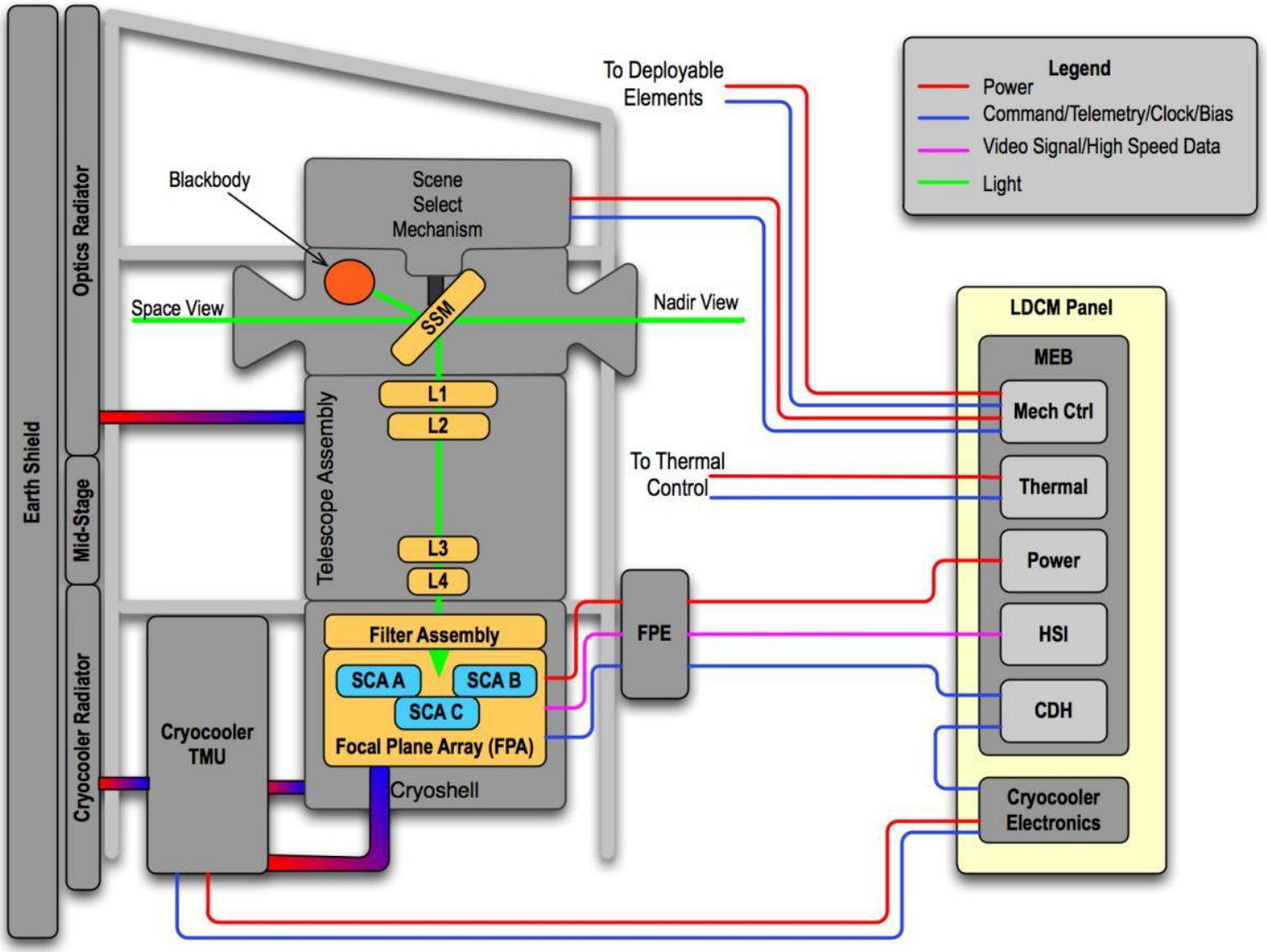
OLI Cut-away



OLI FPA



TIRS Functional Block Diagram



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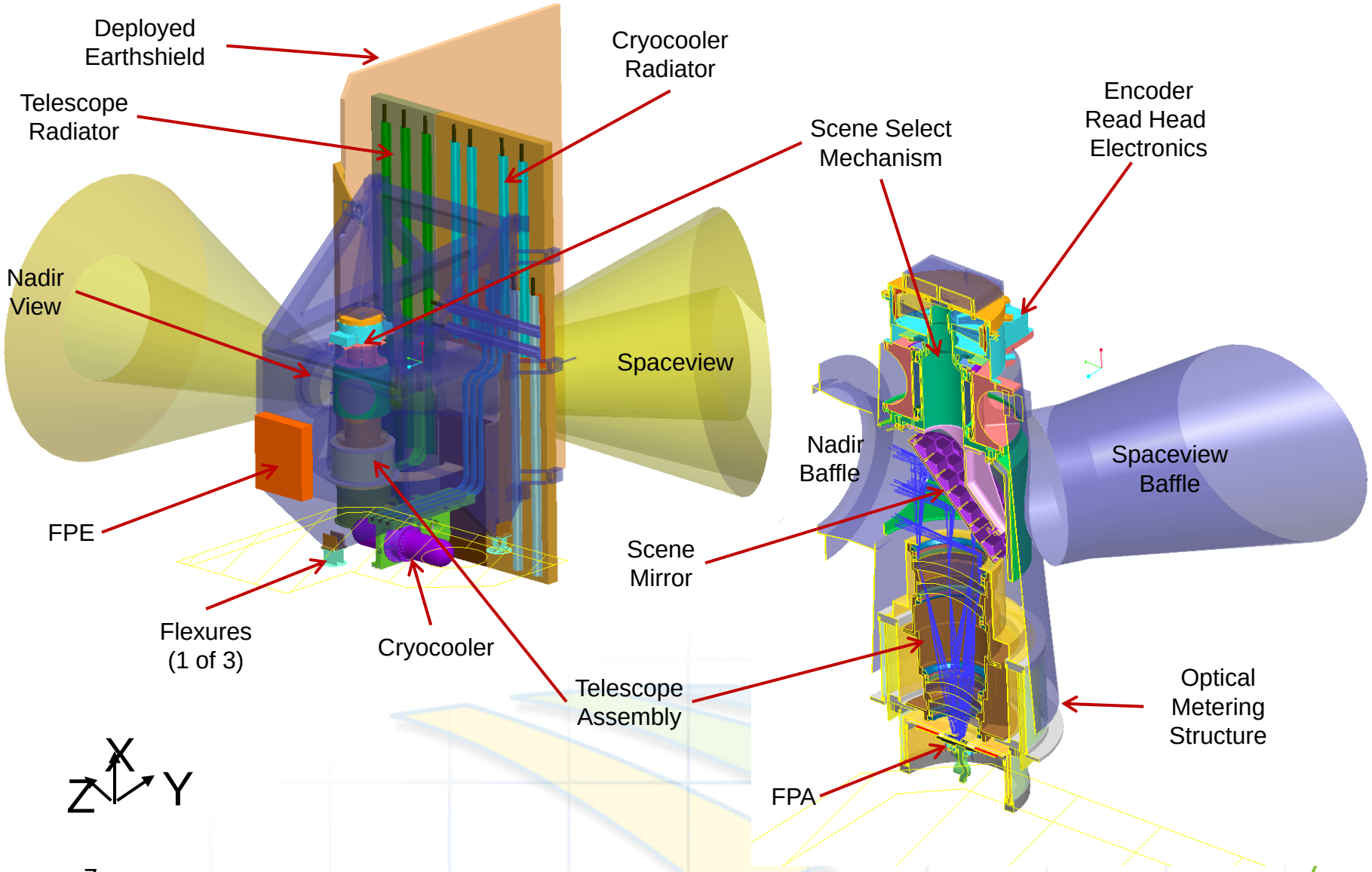
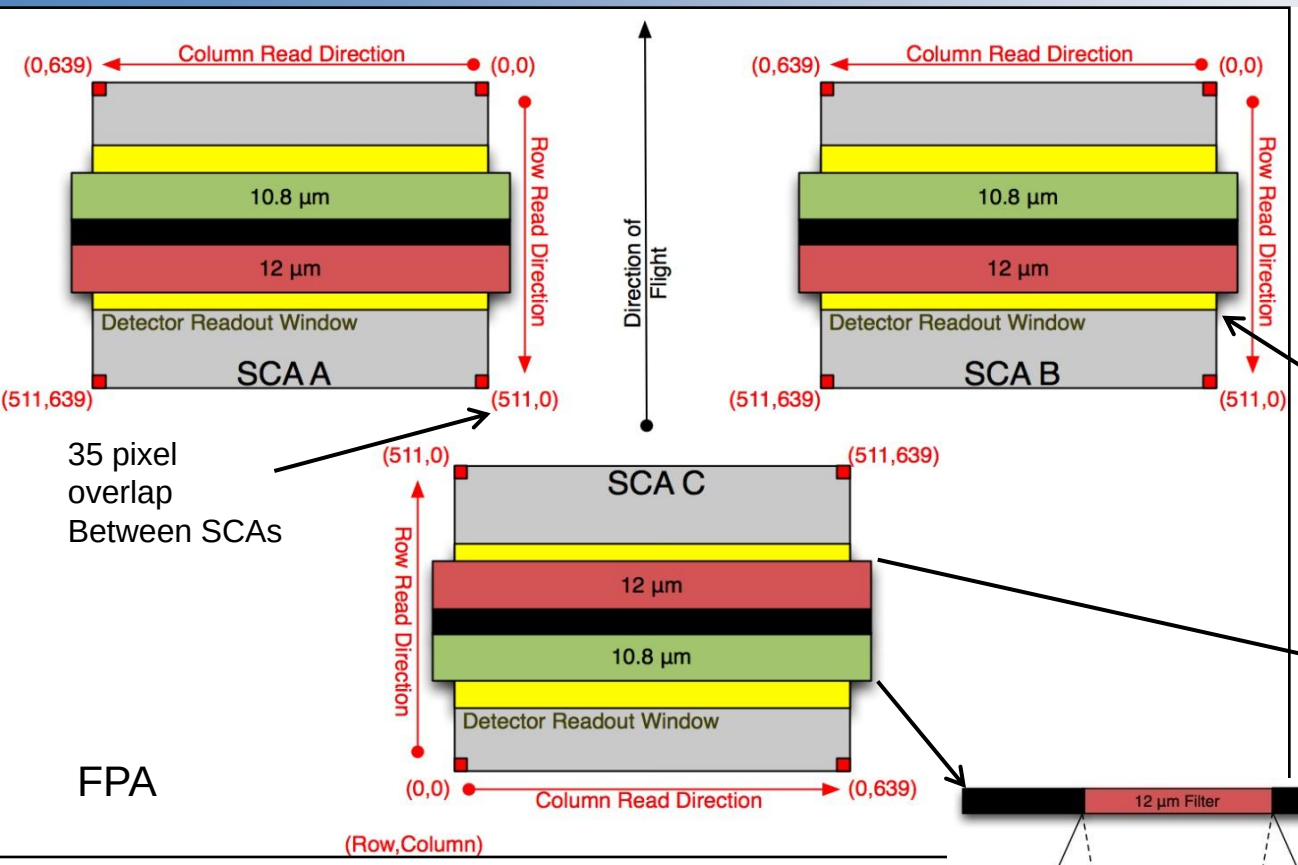
TIRS Sensor Unit Internal View

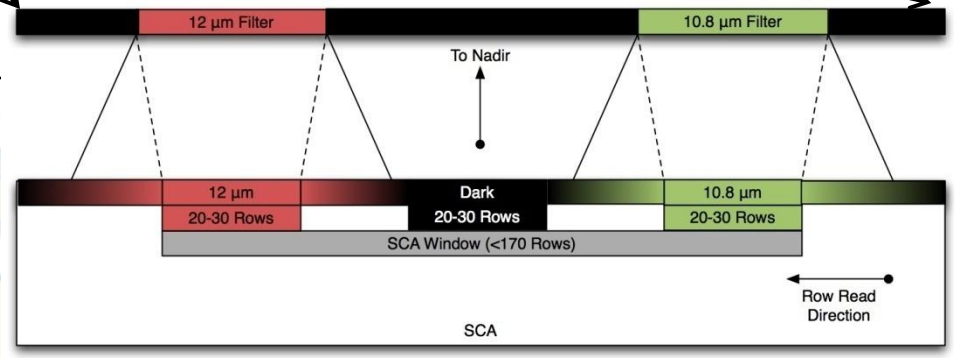


TIRS FPA Architecture



FPA has 1850 unique pixel columns
Corresponds to 185 km swath width
In-track FOV < 5.4 degrees

Filter band locations based on FPA selection . Optimized to best region on FPA.



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Preliminary Orbit and Ascent Plan

Requirements:

- Mission Orbit
  - LDCM is to operate in a Sun-synchronous, near circular, frozen orbit:
    - Equatorial altitude: 705 ± 1 km altitude
    - Inclination: 98.2 ± 0.15°
    - Eccentricity: <= 0.00125
    - MLT-DN: **10:00 a.m. +/- 15 minutes**
    - Ground track error: +/- 5 km cross track error at DN (WRS-2 grid)
    - Repeat cycle: 16 days / 233 Orbits
- Entry operations into the 705-km Constellation to be coordinated with Earth Science Mission Operations (ESMO)

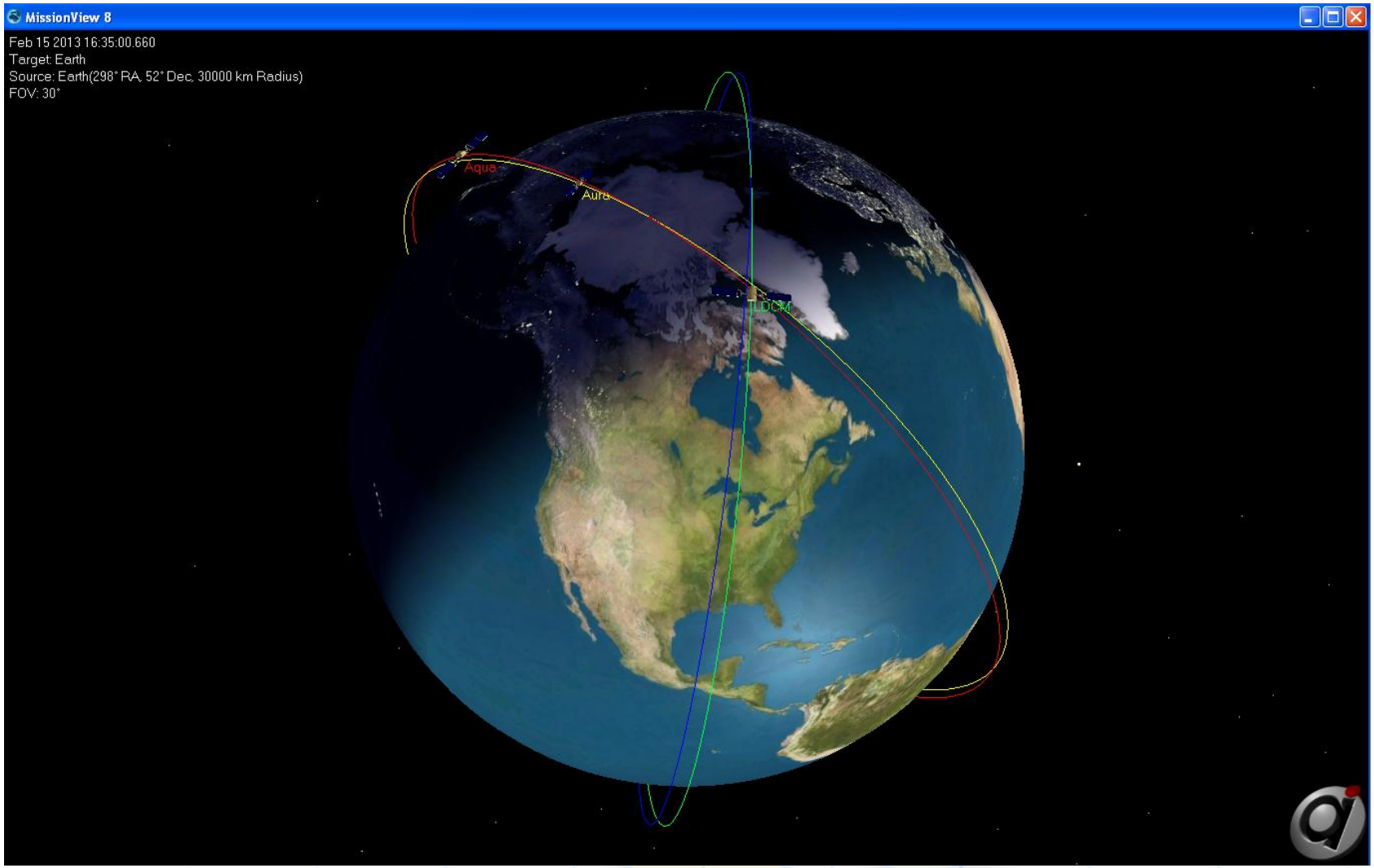
"Desirements":

- Locate LDCM relative to Landsat-7 to produce at 8-day scene phasing (i.e. LDCM images same scene 8-days following Landsat-7; same as Landsat-5 orbit)

Preliminary Orbit: 8-day Phasing, 1014 MLT

- A 8-day phase shift relative to Landsat-7 combined with an MLT shift to 10:14
  - Satisfies the mission requirements
  - Satisfies desire to have an 8-day scene phasing
  - Places LDCM at a safe distance behind the A-Train
  - 40 minutes ahead of L7
  - Terra is approximately 25 minutes behind L7
  - 7.1 minutes behind the A-Train crossing (behind Aura, the caboose)

Orbit Geometry: 8-day Phase

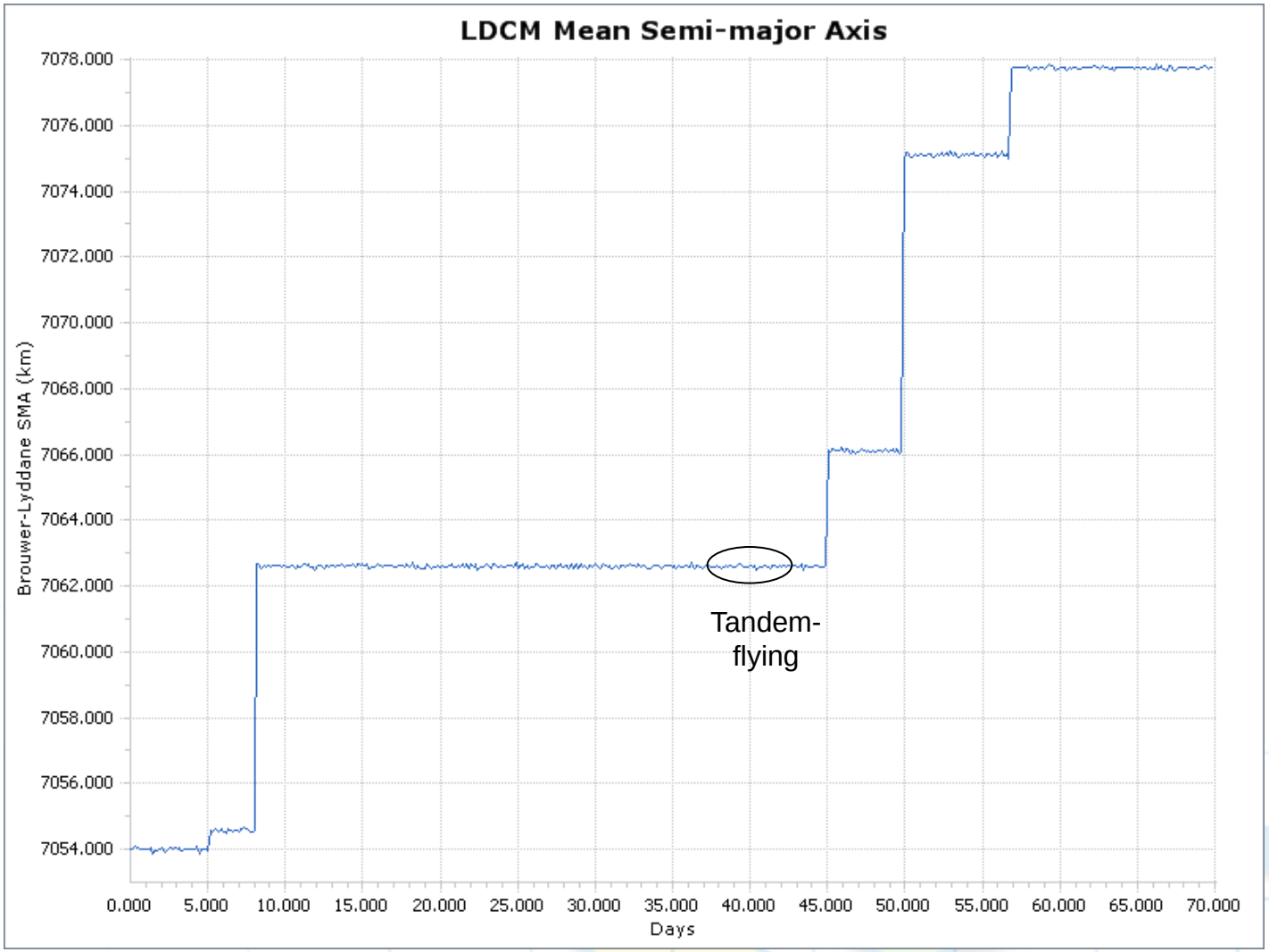


Preliminary Ascent Plan

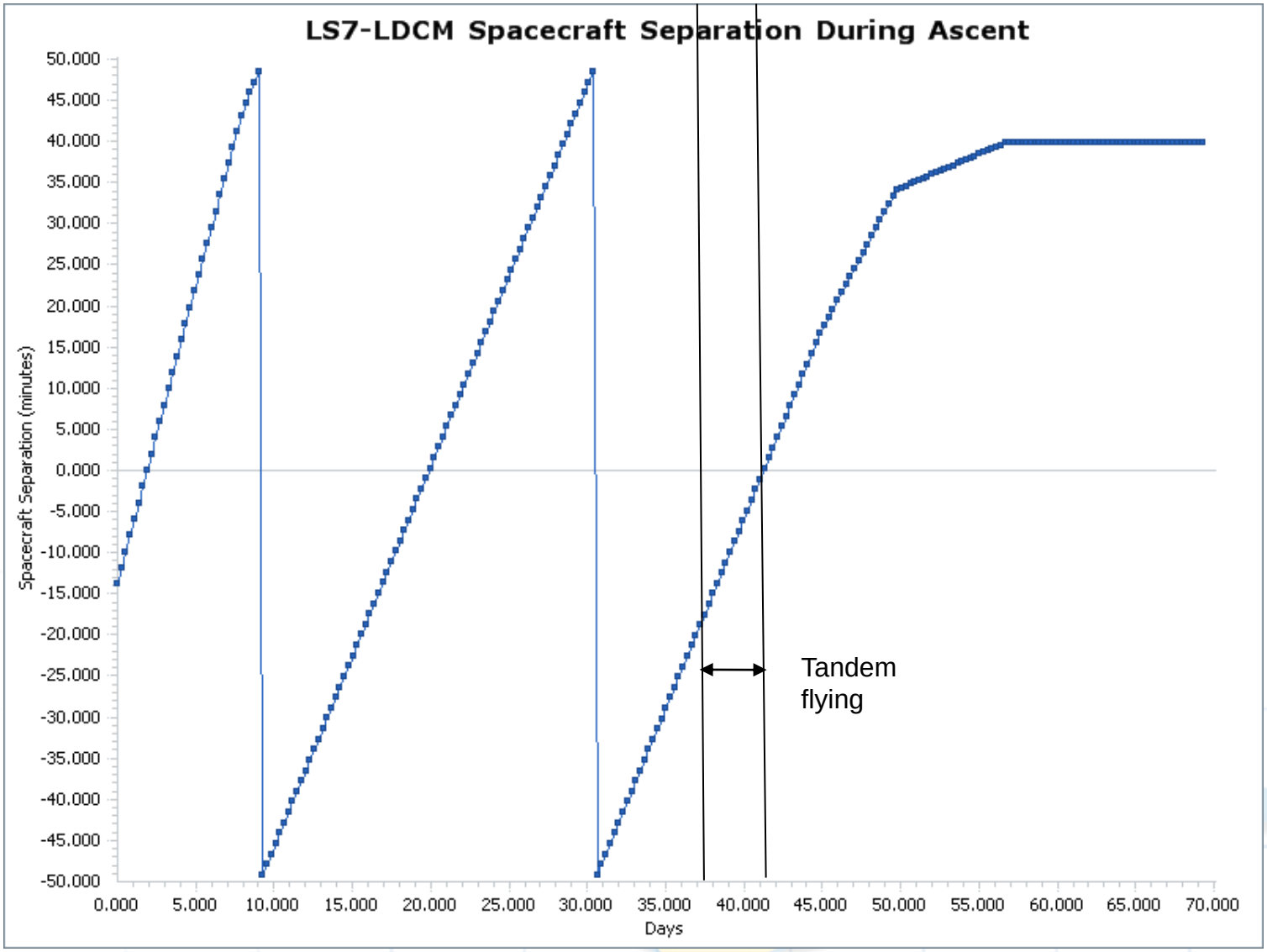
Results

- Sun-synchronous, frozen orbit achieved with 4 ascent burns
- Final crossing is 7.1 minutes behind the A-train
- Tandem flying summary
  - 'Starts' on Day 38
    - LDCM is 18.5 minutes behind L7
    - Begins flying over the adjacent path to the West of L7
  - Flies on the same path on Day 39 – 40
  - 'Ends' on Day 42
    - LDCM is 0.5 minutes behind L7
    - Ends flying over the adjacent path to the East of L7
- Offset due to ~9-minute MLT difference

Orbit Raising Profile



LDCM and L7 Separation (at node crossing)



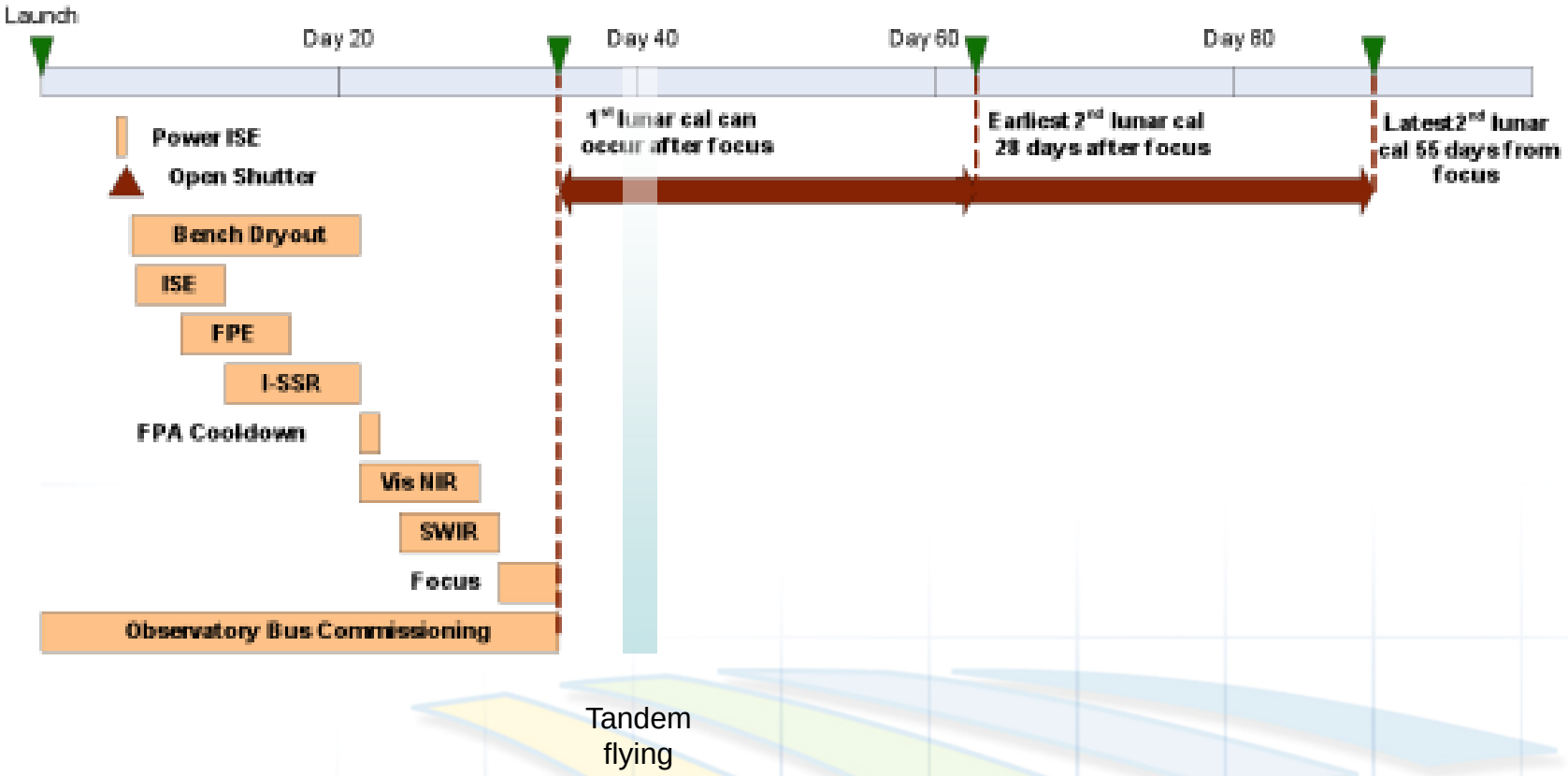
Target Location and Ascent Planning - Going Forward

- Decide on target orbit location relative to Landsat-7
- Continue developing ascent strategy to
  - Account for variations in geometry for 16 launch dates
  - Characterize the tandem flying conditions and determine how much control we have over the timing after launch during the LEO period (to mitigate for delays in instrument tandem flying readiness
- Determine optimum injection MLT (and inclination) to account for drift during ascent
- Establish plans for multiple targets to account for multiple possibilities for location of on-orbit assets at time of LDCM launch:
  - Landsat-7 and Landsat-5 both operational (current plan)
  - Landsat-7 operational / Landsat-5 decommissioned (take L5 spot, with L7 MLT)
  - Landsat-5 operational / Landsat-7 decommissioned (take L7 spot)
  - All decommissioned (avoid the A-Train, locate with consideration of follow-on missions

Commissioning Phase Instrument Activities

- Instrument Suppliers (Ball, TIRS team) lead
  - Activation, focus (OLI)
  - Calibration Acquisitions
  - Update calibration parameters, verify performance
  - Emphasis on geometric performance
  - Changes from pre-launch verifications
- Cal/Val Team shadows instrument suppliers/conduct independent analyses

Preliminary Instrument Activation Plan (OLI)



Commissioning Phase Calibration Acquisitions-OLI

- Dark Acquisitions (twice/orbit)
  - Shutter closed
  - Long Dark – 40 min (5)
- Calibration Site Imaging (all opportunities)
  - Geometric Super Sites
  - MTF sites
  - Radiometric Sites – (monitored, unmonitored)
- Stim Lamp Acquisitions (working-daily, reference-several, pristine-few)
  - Working – Multiple within-orbit collects, within-day collects
- Solar Calibrations (Prime (~20) and Pristine(~3))
  - Normal, Extended, Linearity Time Sweeps
  - Maneuver required
- Lunar Imaging (monthly)
  - All FPM's
  - Specific phase angle required
  - Maneuver required
- Side Slither (weekly)
  - Maneuver required
- Stellar Calibration (twice)
  - Maneuver required

Commissioning Phase
Calibration Acquisitions-TIRS

- Blackbody Acquisitions
  - Normal (twice/orbit)
  - Long Collects – 40 minutes (10)
  - Integration Time Sweep
  - Blackbody Temperature Sweeps
- Deep Space Imaging
  - Normal (twice/orbit)
  - Integration Time Sweep
- Calibration Site Imaging (all opportunities)
  - Geometric Super Sites
  - Radiometric Sites
- Lunar Imaging (TBR)
- Side slither (TBR)

On-Orbit Relative Gain Characterization/Calibration

- Intended Primary Methods
  - OLI
    - Solar Diffuser Detector Average Responses –bias corrected (~8 days)
    - Diffuser Non-Uniformity from pre-launch characterization
      - OLI Relative gains from yaw scans of calibration sphere (DSS)
      - Diffuser non-uniformity characterized with OLI as transfer instrument
  - TIRS
    - On-board blackbody and deep space views (2/orbit)
    - Blackbody non-uniformity characterized with TIRS as transfer instrument
- Alternate methods
  - Side-slither—within FPM (monthly to quarterly) – TIRS [TBR]
  - FPM overlap statistics – between FPM's (acquired every scene)
  - Cumulative Histograms (acquired every scene- analyzed weekly to monthly)
  - Stim lamp statistics – (acquired daily) – OLI only

On-Orbit Absolute Calibration

- OLI
  - Radiance
    - Initial diffuser view versus predicted response from heliostat and atmospheric correction vs instrument assumed stable through launch
    - Validation/check
      - Diffuser reflectance and solar curve
      - Vicarious sites
  - Reflectance
    - Prelaunch measured reflectance of diffuser
  - Trends from **lunar**, diffuser (prime, **pristine**), stim lamps (prime, reference, pristine) and PICS
- TIRS
  - Blackbody and deep space views
  - Validation/check
    - Vicarious sites

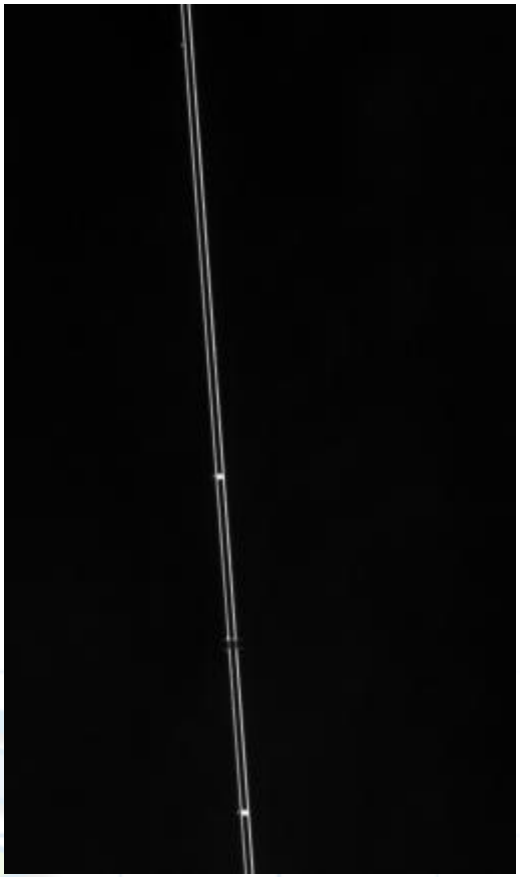
Other On-Orbit Radiometric Characterizations

- OLI
  - Linearity – Integration time sweeps with solar diffuser and shutter
  - Noise
    - SNR-solar diffuser, stim lamps
    - Coherent and 1/f noise – long darks
  - Stability
    - Long darks, extended solar collects, multiple lamps per orbit, trending
- TIRS
  - Linearity –
    - Integration time sweeps with black body & deep space
    - Varying black body temperature over multiple orbits
  - Noise
    - NEdL – black body, deep space
    - Coherent and 1/f – long collects
  - Stability
    - Long collects, trending

On-orbit Spatial Characterization – Earth

- The CVT will analyze images of the Lake Pontchartrain causeway to estimate OLI on-orbit edge response slope performance
  - Same method used to monitor on-orbit L7 ETM+ MTF degradation
  - Single image results are subject to fairly large measurement error
    - ETM+ MTF estimates are repeatable to 3-9% depending on the band
  - Will require multiple cloud-free images to obtain meaningful results
  - Only provides a performance measure at one location in the OLI FOV
  - May provide only a sanity check during commissioning due to small number of usable scenes (depends on cloud cover)
- The bridge was found to be too small to be useful for Landsat 7 thermal band characterization so it will not be useable for TIRS

- Pontchartrain Causeway (ALI pan band)

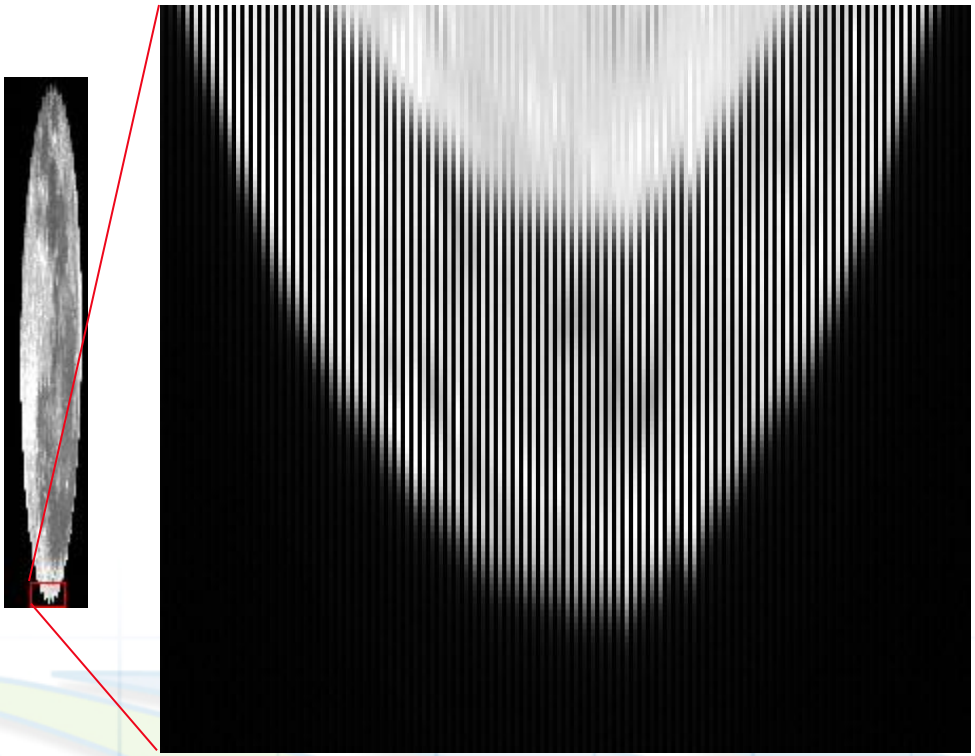


On-orbit Spatial Characterization - Lunar

- Lunar scans will also be used to estimate on-orbit spatial performance
  - Technique developed for ALI, but only tested on a few images
  - Provides along- and across-track estimates from the same target
  - Better distribution across the OLI FOV than bridge target (one scan per SCA)
  - Provides results for all bands (including cirrus)
- TIRS will also image the moon
  - May need to work around saturation issues

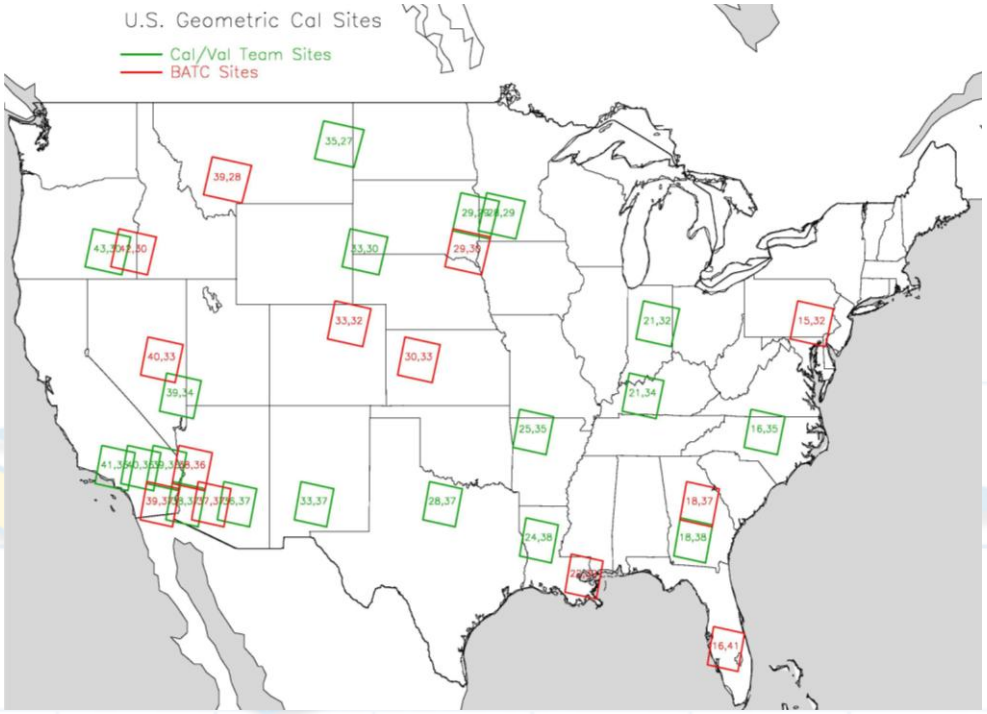
- Lunar Scan

  (ALI pan band 8X oversample scan)



On-orbit Geometric Characterization and Calibration Sites

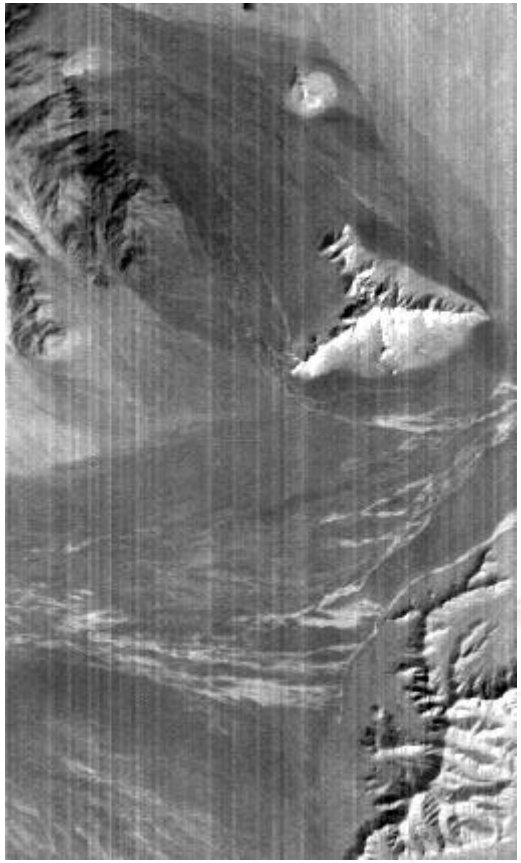
- On-orbit characterizations are performed using geometric calibration test sites where supporting data are available
  - GCPs, DEMs, DOQ or SPOT reference images
  - Site distribution is such that at least one site is visible each WRS-2 cycle day and at least 4 sites are visible over any two consecutive WRS-2 cycle days
- BATC has been provided with a set of test sites
  - The CVT will analyze additional test sites to verify BATC results



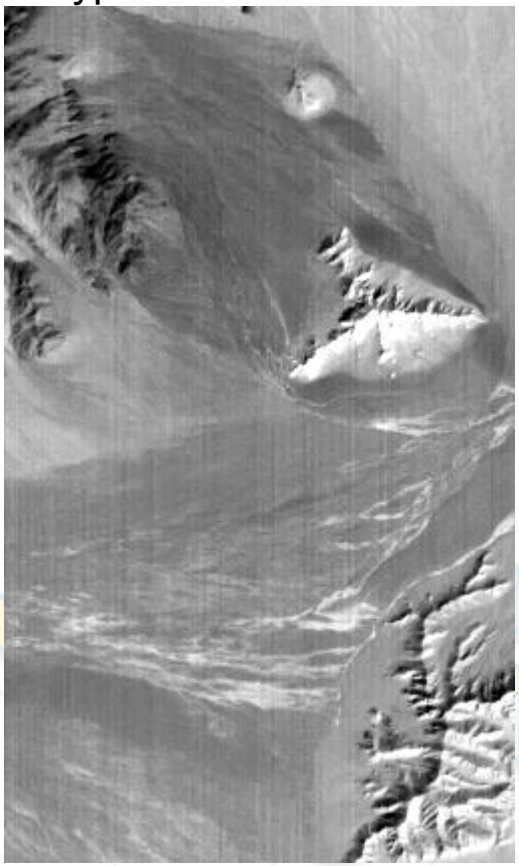
On-Orbit Band Alignment Calibration

- Band alignment calibration uses winter season desert sites to align the multispectral bands to the pan band
  - BATC special study used Hyperion data to show that this will also work for the cirrus band using sites at suitably high elevation

- Hyperion “Cirrus” Band



- Hyperion “SWIR1” Band



- GloVis Location Plot

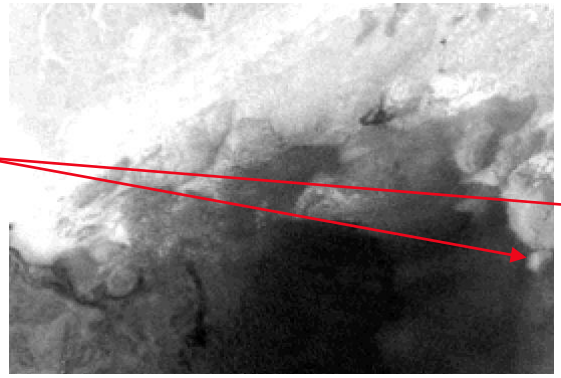
Thermal to SWIR Band Registration

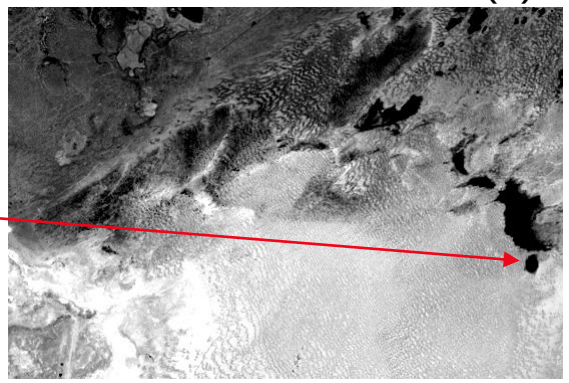
L7 ETM+ Thermal Band (6)

L7 ETM+ SWIR1 Band (5)

Summer

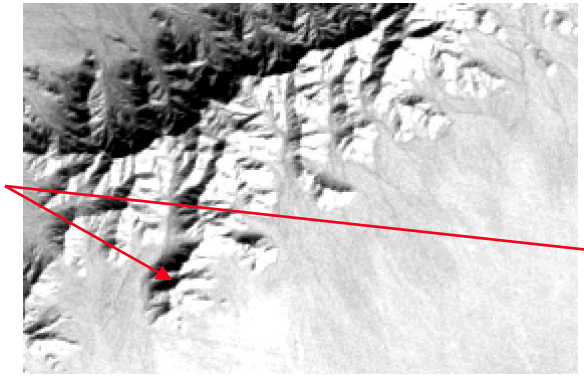
- High temperatures
  - => Contrast reversal
- High sun angles
  - Fewer shadows

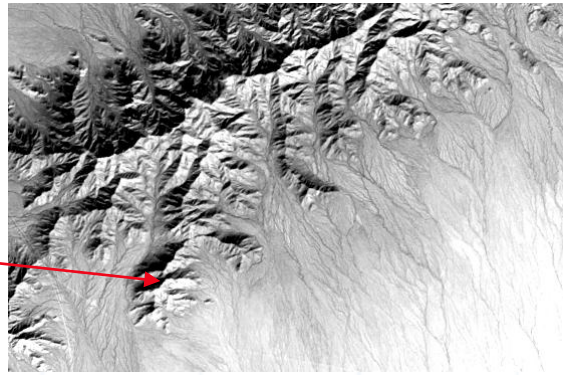




Winter

- Lower temperatures
- Lower sun angles
  - More (cool) shadows





Current thermal to reflective band registration performance prediction meets requirement

- Calibration accuracy is a driver

Thermal - Reflective Band Registration			
	Allocation	CBE	
Contribution	LE90	LE90	Margin
OLI	5.86	5.29	11%
S/C	11.77	3.17	271%
TIRS	12.66	11.27	12%
Processing	3.88	3.56	9%
OLI-TIRS Cal	23.49	15.93	48%
Net	30.0	20.8	44%

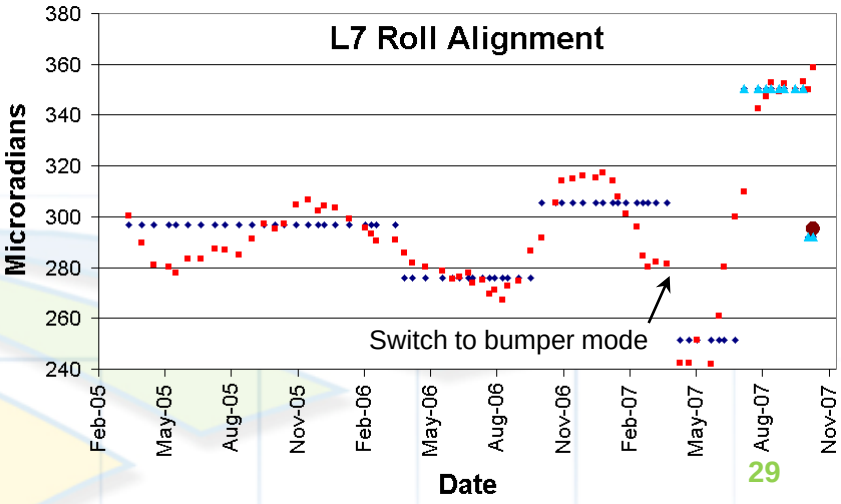
all values in meters

TIRS Alignment Calibration

- New algorithm developed for TIRS
  - Combines functions of two OLI heritage algorithms:
    - Focal plane calibration – refine relative locations of SCAs
    - Sensor alignment calibration – determine relationship between instrument and spacecraft attitude control system
- Uses TIRS-to-OLI band-to-band measurements to determine TIRS-to-OLI alignment matrix and TIRS SCA-specific adjustments
- TIRS-to-ACS alignment is determined indirectly as a composite of the TIRS-to-OLI and OLI-to-ACS alignment matrices
  - TIRS-to-OLI alignment knowledge is more important than TIRS-to-ACS alignment since it determines thermal-to-reflective band registration accuracy

Calibration Parameter On-Orbit Update

- A select set of OLI and TIRS geometric calibration parameters will be refined on-orbit if necessary
  - LOS model parameters will be updated during commissioning if necessary using OLI focal plane alignment, OLI/TIRS band alignment, and TIRS alignment calibration tools
    - These LOS model parameters will be monitored operationally but are not expected to change frequently if at all
      - L7 band alignment was updated twice on-orbit (after launch and after the scan line corrector failed)
  - The OLI-to-ACS sensor alignment calibration and the TIRS-to-OLI sensor alignment calibration will be updated during commissioning and as necessary operationally to maintain geodetic accuracy performance
    - L7 ETM+ sensor alignment is updated quarterly to compensate for seasonal thermal effects
- Earth orientation parameters are downloaded from USNO and updated quarterly



Operations Phase
Calibration Acquisitions-OLI

- Dark Acquisitions (twice/orbit)
  - Shutter closed
  - Long Dark – 40 min (quarterly
- Calibration Site Imaging (as available)
  - Geometric Super Sites
  - MTF sites
  - Radiometric Sites (monitored, unmonitored)
- Stim Lamp Acquisitions (working-daily, reference-monthly, pristine-1/6 months)
  - Working – Quarterly within-orbit collects
- Solar Calibrations (Prime (1/8 days) and Pristine(1/6 months))
  - Normal, Extended, Linearity Time Sweeps
  - Maneuver required
- Lunar Calibrations (monthly)
  - Specific phase angle required
  - Maneuver required
- Side Slither (monthly)
  - Maneuver required

Operations Phase
Calibration Acquisitions-TIRS

- Blackbody Acquisitions
  - Normal (twice/orbit)
  - Long Collects – 40 minutes (quarterly)
  - Integration Time Sweep (monthly)
  - Blackbody Temperature Sweeps (monthly)
- Deep Space Imaging
  - Normal (twice/orbit)
  - Integration Time Sweep (monthly)
- Calibration Site Imaging (as available)
  - Geometric Super Sites
  - Radiometric Sites (monitored, unmonitored)

Backup Slides

Routine Characterizations and Calibrations: Acquisitions

- Geometric Performance

Performance / Acquisition	Band-to-Band Registration (Within & between instruments)	Geodetic Accuracy (Change monitoring)	Spatial Performance
OLI Stellar (Commissioning Only)	X	X	
OLI Lunar			X
Geometric Super-sites	X	X	
Spatial Sites			X

- Radiometric Performance

Performance / Acquisition	Detector-to-Detector Relative Calibration	Long Term Stability (Change Monitoring)	Absolute Calibration (Geophys Param Retrieval)
OLI Dark (Cal Shutter)	X	X	X
OLI Solar Diffuser	X	X	X
OLI Side-Slither	X		
OLI Lamps		X	
OLI Vicarious Sites			X
OLI Pseudo-Invariant Sites		X	
OLI Lunar		X	
TIRS Dark (Deep Space)	X	X	X
TIRS Blackbody	X	X	X
TIRS Vicarious Sites		X	X

Red - spacecraft operations (maneuver)
Blue - instrument mechanism operations
Black - scheduling only

Routine Characterizations and Calibrations: Acquisitions (con)

- Geometric Performance
  - OLI, TIRS Geometric Super Site Acquisitions (every WRS cycle)
  - OLI Stellar Observation (commissioning only)
  - OLI Lunar Observations (~monthly)
- Radiometric Performance
  - OLI
    - Shutter (2x/orbit)
    - Lamp (daily-prime; weekly-reference; twice-yearly-pristine);
    - Solar Diffuser (~weekly-prime; twice yearly-pristine)
    - Side Slither (~weekly ➔ quarterly)
    - Lunar (~monthly)
    - Pseudo-Invariant Sites (every WRS cycle)
    - Vicarious (all opportunities during commissioning; quarterly afterwards)
  - TIRS
    - Deep space port observations (2x/orbit)
    - Blackbody Observations (2x/orbit);
    - TIRS monitored sites (all opportunities)